OMRON

Vision Sensor

Technology overview
Pattern Matching Algorithm
Shape search Ⅲ

Think & See

Technology
Introduction
Guide

Q199-E1-01

Think & See™ Technology

OMRON is continuously conducting research & development aiming at so fast and accurate image-based sensing technologies that transcend human vision system by far. For this we are researching state-of-the-art image processing, machine learning, numerical optimization and recent implementation techniques. Applying these technologies, we are producing essential infrastructures in broad domains such as not only factory automations (FA), but video surveillances, intelligent transportation systems (ITS) and people/faces/gestures/animals sensing on mobile devices, as in Fig.1. Think & See technologies are those powerful core technologies behind these applications.

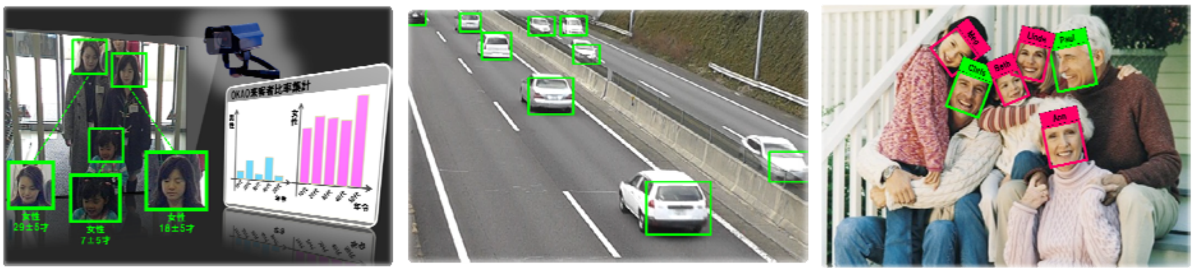


Fig.1. (left) video surveillances, (middle) ITS, (right) facial image processing

Recent advances in image-based pattern matching applied to FA

In manufacturing lines/machines in factories, image sensors have been widely used for flaw detection, object detection and alignment, etc. In image sensors, pattern matching is one of fundamental functions to search user-defined patterns in an input image and calculate positions and poses of found patterns. The function can be used for product inspection (head/tail detection or just existence check of parts, etc.), position compensation and target position/pose detection for machine control or higher-level inspection.

Examples of the machines include pattern deposition machines in semiconductor industries, bonding of glass substrate in FPD (Flat Panel Display) industries, etc. Continuous progress for miniaturization in these industries nowadays involves μ-order measurements. Furthermore, it requires robust detection under severe conditions e.g., low-contrast, blur, degraded patterns, multiple pattern overlapping due to layer stack of materials. In addition to these requirements, pursue for machine efficiency requires single ms-order so fast processing.

The other observations of recent manufacturing scenes include advances of prevailing industrial robots for palletizing and assembly of parts. Amongst them, parallel link robots, which are characterized by their fast motion via simple mechanisms, are getting much popularity, attracting many robot manufacturers. In robotic applications image sensors generally serve as apparatuses to guide position/pose of parts. However, these applications involve highly robust and stable detection resistant to inconsistent illumination/shading, halation due to specular reflection, touching or overlapping of multiple targets. They also requires high speed processing to deal with typically 200 – 400 pieces per minute.

Shape search III based on Think & See technology is our answer for these emergent demands in state-of-the-art manufacturing scenes.

Roughly speaking, pattern-matching algorithm in FA fields can be divided into two functional blocks; one is search function to find out user-defined patterns, and the other is precise alignment function to estimate position/pose in sub-pixel/degree order. Fig.2 illustrates recent advances of these technologies. The latest research work shows that utilizing only characteristic features that can be stably extracted could be better choice than utilizing whole features from the target shape in terms of speed and accuracy, which means large portion of densely extracted features do not affect significantly detection accuracy or are sometimes harmful. We refer to these selected features as “sparse features”. Utilizing edge-based sparse features, the shape search III is achieving very fast yet highly accurate target detection. Furthermore, computing optimal shift/rotation parameters by minimizing summed errors on corresponding points between a model and an input image, it is realizing highly precise alignment robust to missing or deformed edges.

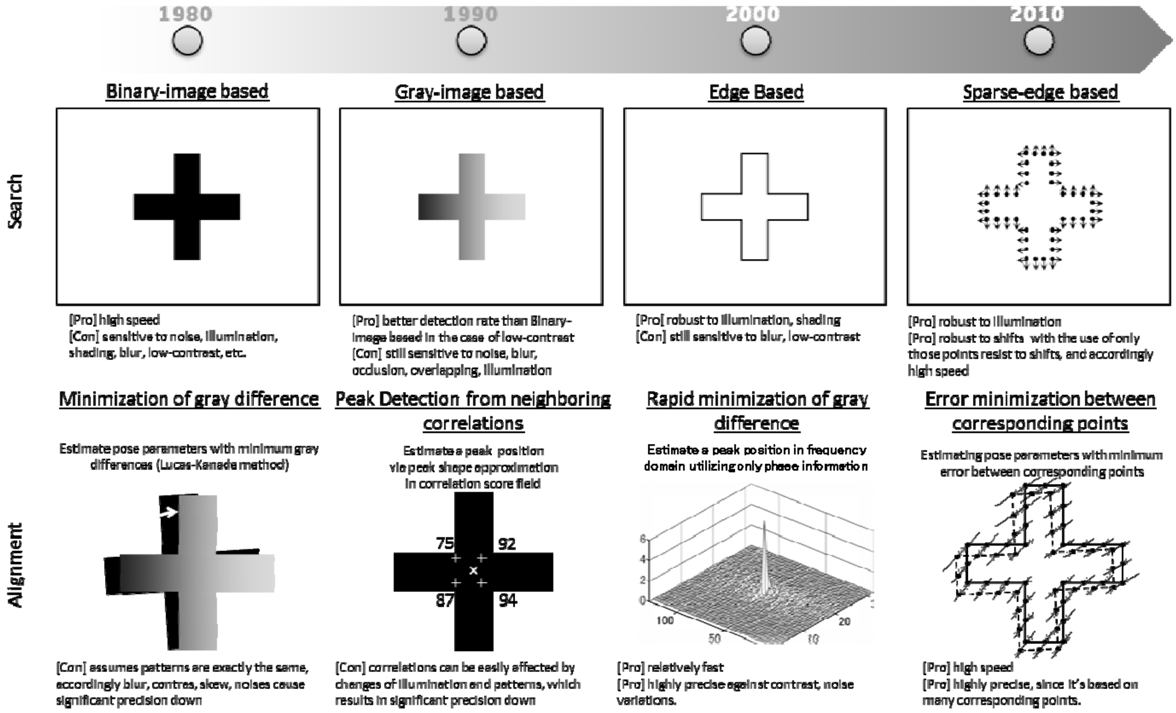


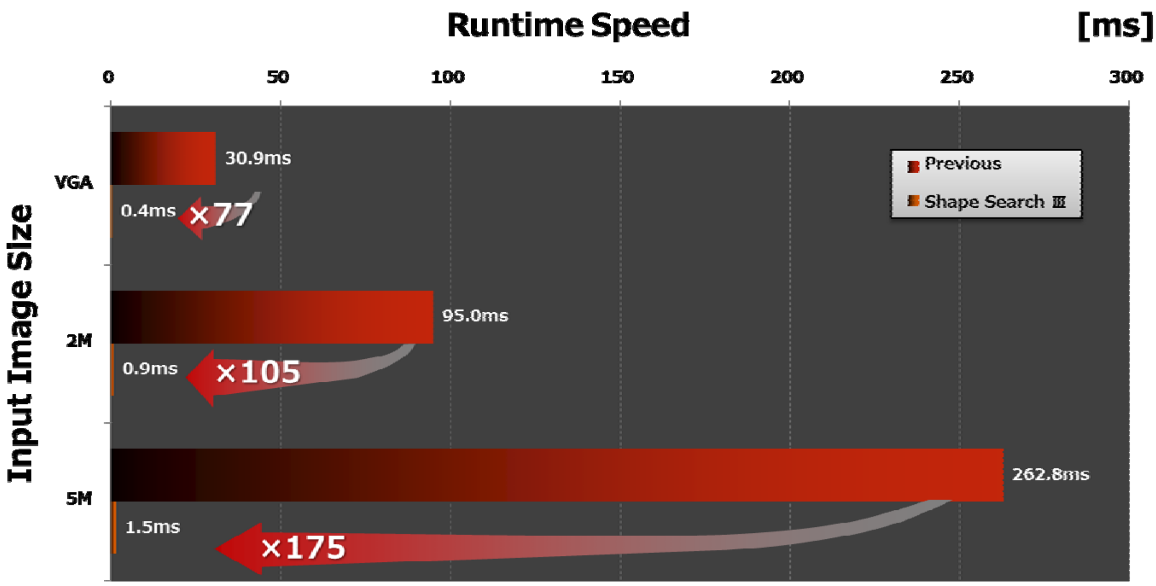
Fig.2. technology advancement in pattern matching applied to FA fields

Features of the Shape Search III

1. Ultra-fast matching speed

The shape search III speeds up our previous algorithms (simple edge-based) drastically. Fig.3 shows an example of such speed-ups. Especially when high-resolution cameras are employed, it realizes more than 100 times speed-up compared to the previous one. In the case of VGA cameras, even 1000 fps high speed processing can be realized.

Edge-based sparse features and parallel processing are key techniques for this drastic speed-up. Let's see these techniques in detail.



* Target: a cross mark ("+"), Search area: whole image area, Rotation tolerance: +/- 10 degree

Fig.3. runtime speed measurement results (on Intel Core^{TM} i7 3770K)

Edge-based sparse features for high-speed matching

Shape search III, utilizing only selected edges that are consistent under noises and geometric deformations, etc. rather than entire observed edges on all pixels from target area, realized both high-speed processing and robustness against these bad conditions at the same time. The feature selection is optimized to artificial objects typically seen in factory automation scenarios. Fig.4 depicts selected edge points by green dots; left pane shows noisy edges inconsistent through target variations, while right pane shows sparse features after removing these inconsistent edges. Exploiting only these selected edges yields significant speed-up and accuracy improvement as well.

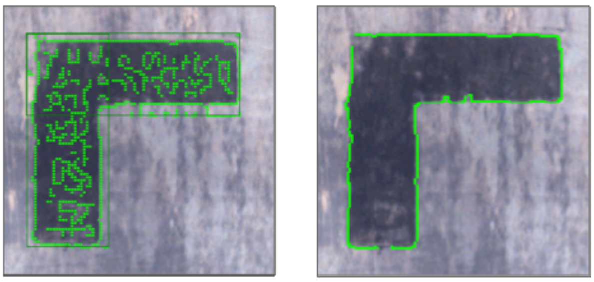


Fig.4. (left) features including noisy edges, (right) sparse edge features

Parallel processing exploiting recent PC architecture effectively

Recent progress of PC architectures such as increasing frequency count and multi-core/thread technologies can benefit computational efficiency. Our new FH system is exploiting these latest architectures and shape search III is successfully deriving the potential of PC architecture by parallel processing multi-core/thread, SIMD instruction. Especially repeated computation that typically happens in image processing can be significantly speeded up by these implementations.

2. Highly accurate detection

Applications in deposition machines, bonding machines, etc., may involve many severe conditions such as blur/low-contrast/missing/occlusions of edges, complicated backgrounds, size changes, and overlapping of multiple patterns. Shape search III, however, realizes high detection rate even under these severe conditions as illustrated in Fig.5.

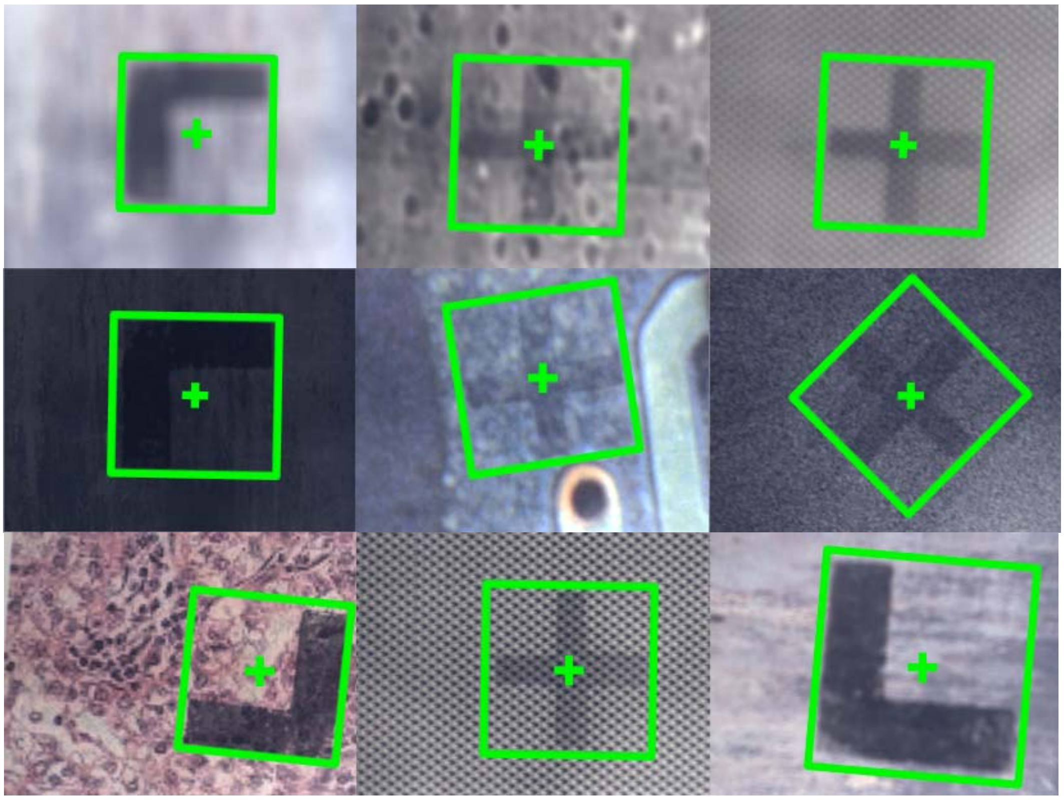


Fig.5. some examples of accurate detection under severe conditions; (upper) blur, (middle) low-contrast and noises, (lower) complicated backgrounds and scale change, where green bounding boxes indicate detected position.

Quantitative results can be seen in Fig.6. Since these are detection accuracy, the larger, the better. The test dataset used in the evaluation can be seen in Fig.7 with detection results. From these results, one can see that the detection accuracy is drastically improved especially for severe situations such as blur, low contrast and size (scale) changes.

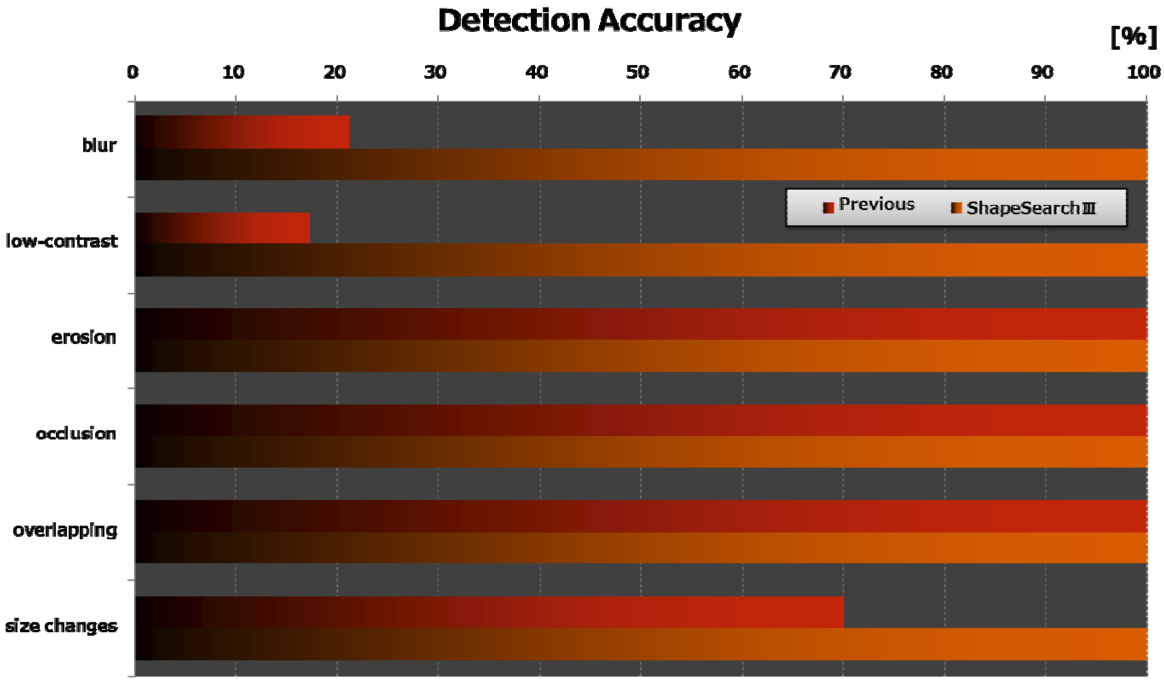


Fig.6. detection accuracy comparison

Fig.7. some examples of images used in evaluation, from left, blur, low-contrast, erosion, occlusion, overlapping and size change, where green bounding boxes mean detected position.

The variation-absorbing template method is one of key technologies to achieve these high detection rates, which is described in the next section.

The variation-absorbing templates method for high detection rates

Our previous search algorithm with dense edge features was easily affected adversely by slight changes of edge configurations, and thus slight appearance changes due to swells of conveyers, slight dimensional variation of targets, etc., easily caused stability degradation of detection accuracy and sometimes brought mysterious behaviors. One possible solution for such phenomena could be iterative matching with multiple templates (with different appearances), which in general results in significant speed down. It means a trade-off between accuracy and speed. To this end, we developed so-called "variation-absorbing templates" (now under patent application). The method is, as illustrated in Fig.8, to generate several 10 thousands of possible variations in each local region to absorb appearance changes by these variations. On the other hand, huge amount of generated templates are intelligently clustered and aggregated into a set of groups based on their appearance similarity, which results in 1/100 to 1/1000 memory reduce compared to the original size of generated templates. Thus it does not cause intensive memory consumption or speed-down but just benefits better accuracy. In this way, the new algorithm realizes highly accurate detection and high-speed processing at the same time.

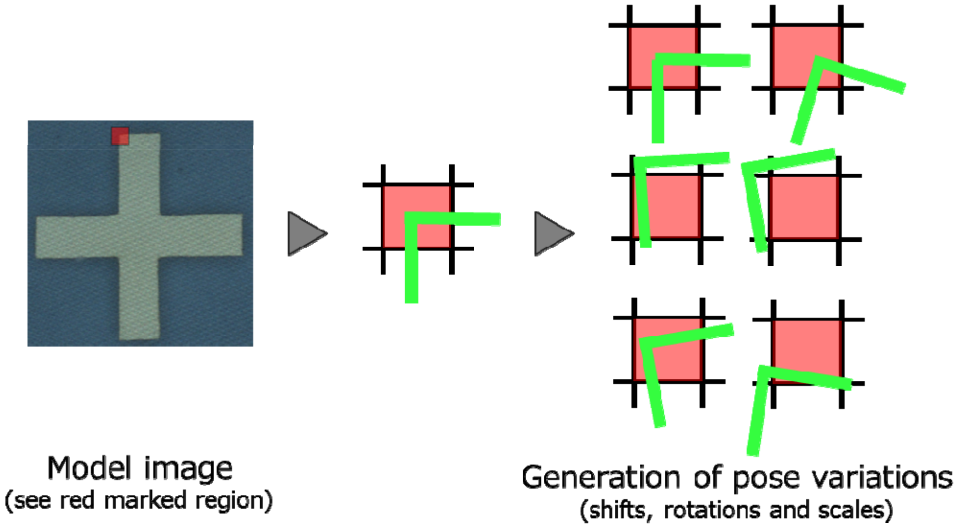


Fig.8. the variation-absorbing templates method

3. Highly precise alignment

For alignment precision, computing position/pose parameters by minimizing summed errors over corresponding points, we have developed a new optimal algorithm in least square sense. The new algorithm achieves 1/100 pixel-order precision, which is 10 times more precise compared to the previous one via peak detection utilizing correlation scores in the vicinity. Fig.9 draws precision comparison. Through the evaluation, we just added simulated camera noises. Some examples of evaluated data can be seen in Fig.10.

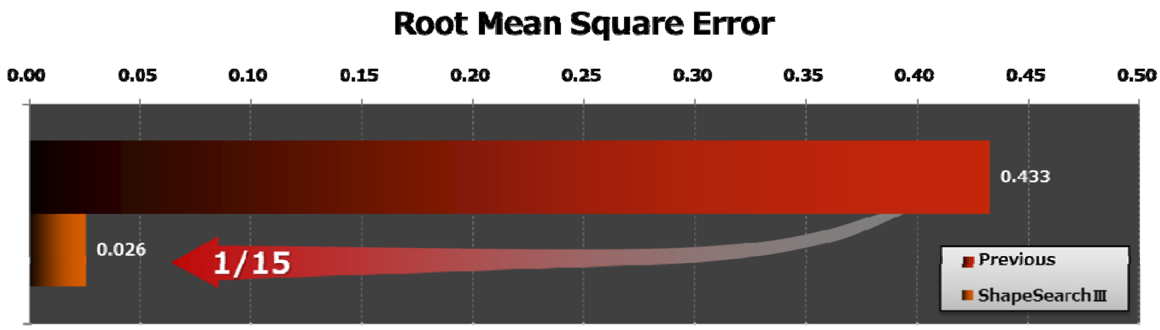
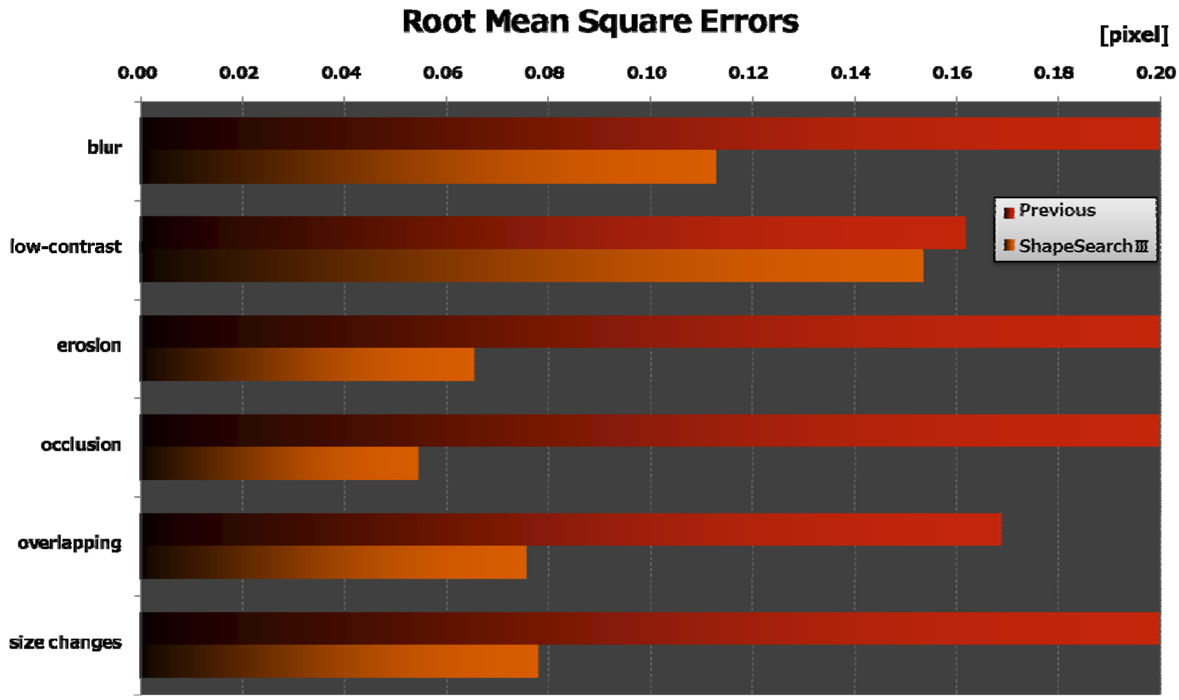


Fig.9. root mean square error under normal setting

Fig.10. some examples of evaluated data

This result is for ideal situations. More practical setting may involve much severer conditions such as blur, low-contrast, missing points, occlusions of edges, complicated backgrounds, overlapping of multiple patterns and their combinations. The shape search III, however, even in such severe conditions as illustrated in Fig.7, achieves high precision. Note that Fig.7 shows relatively easier samples for visualization and evaluation dataset contains much more difficult samples. (Actually, for example, in the worst low-contrast condition, it is very challenging even for human to find the pattern). The evaluation results can be seen in Fig.11. Note that these measurements are conducted over detected samples; the detection rate is figured in Fig. 6. Since precision measurement is a post-processing of the detection, those samples for which the detection rate of the previous algorithm is failed are removed from measurement in Fig.6. In the case, the population for evaluation tends to become a set of very easy samples. These phenomena should be taken into account.



* Input image size: VGA, Target: a cross pattern with translated by 0.1pix.

Fig.11. precision comparisons under practical setting

4. Nice visualization for deriving best performance

In our previous products, users are required to tune many parameters and their combinations through trial-and-error to derive best potential performance of the algorithm. The shape search III resolves this by visualizing internal status of the algorithm. For instance, as illustrated in Fig.12, by visualizing local matches between edges of the model and those of an input image, users can easily optimize parameters such as edge magnitude threshold, edge computation block size, etc., so that the unmatched edges can be matched properly. This significantly alleviates burdens on users for optimization.

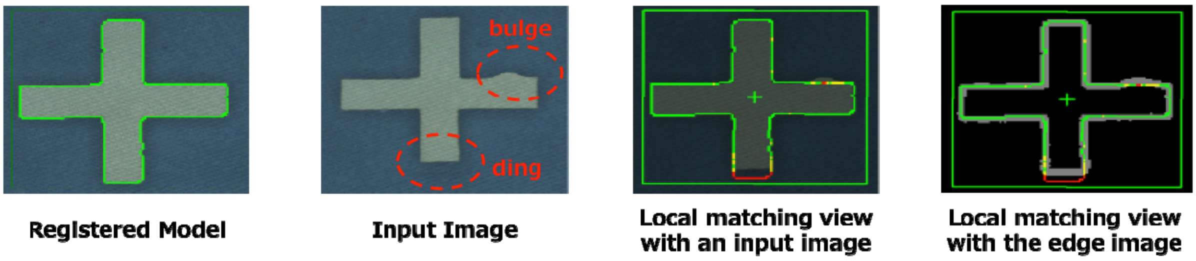


Fig.12. visualization of local matches

Future work

The Shape Search III based on Think & See technology has achieved drastic performance advancement in terms of speed, accuracy, precision and usability. Furthermore, its robustness enhancement has widened range of applications. However, performance optimization with respect to entire systems or increasing further the range of applicable targets and conditions such as deformable objects, objects with appearance changes, etc., still remains big problem. As described before, Think & See technologies are already applied to vast industrial fields beyond FA fields and can be applied to the other fields either, which means our potential to solve many difficult problems in factory automation field.

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